# UNITED STATES PATENT APPLICATION

OF

SHAWN FERRON

JOHN KELLY

AND

ROBBERT VERMEULEN

FOR

# APPARATUS AND METHOD FOR CONTROLLED COMBUSTION OF GASEOUS POLLUTANTS

## BACKGROUND OF THE INVENTION

### Field of the Invention

[0001] The present invention relates to systems and methods for thermal treatment of industrial effluent fluids such as effluent gases produced in semiconductor manufacturing while reducing deposition of reaction products in the treatment systems.

### Description of the Related Art

[0002] The gaseous effluents from the manufacturing of semiconductor materials, devices, products and memory articles involve a wide variety of chemical compounds used and produced in the process facility. These compounds include inorganic and organic compounds, breakdown products of photo-resist and other reagents, and a wide variety of other gases that must be removed from the gaseous waste streams before being vented from the process facility into the atmosphere.

[0003] Semiconductor manufacturing processes utilize a variety of chemicals, many of which have extremely low human tolerance levels. Such materials include gaseous hydrides of antimony, arsenic, boron, germanium, nitrogen, phosphorous, silicon,

selenium; silane; silane mixtures with phosphine, argon, hydrogen; organosilanes, halosilanes, halogens and other organic compounds.

[0004] Halogens, e.g., fluorine ($F_2$) and fluorinated compounds are particularly problematic among the various components requiring abatement. The electronics industry uses perfluorinated compounds (PFCs) in wafer processing tools to remove residue from deposition steps and to etch thin films. PFCs are recognized to be strong contributors to global warming and the electronics industry is working to reduce the emissions of these gases. The most commonly used PFCs include $CF_4$, $C_2F_6$, $SF_6$, $C_3F_8$, and $NF_3$. These PFCs are dissociated in a plasma to generate highly reactive $F_2$ and fluorine radicals, which do the actual cleaning, and etching. The products from these processing operations include mostly fluorine, silicon tetrafluoride ($SiF_4$), and to a lesser extent hydrogen fluoride (HF), carbonyl fluoride ($COF_2$), $CF_4$ and $C_2F_6$.

[0005] A significant problem has been the removal of these materials from effluent gas streams of semiconductor manufacturing processes. While virtually all U.S. semiconductor-manufacturing facilities utilize scrubbers or similar means for treatment of their effluent gases, the technology employed in these facilities is not capable of removing all toxic or otherwise unacceptable impurities.

[0006] One solution to this problem is to incinerate the process gas to oxidize the toxic materials, converting them to less toxic forms. Such systems are almost always over-designed in terms of its treatment capacity, and typically do not have the ability to safely

deal with a large number of mixed chemistry streams without posing complex reactive chemical risks. Further, conventional incinerators typically achieve less than complete combustion thereby allowing the release of pollutants to the atmosphere including carbon monoxide (CO) and hydrocarbons (HC). Furthermore, one of the problems of great concern in gas effluents is the formation of acid mist, acid vapors, acid gases and NOx (NO, $NO_2$). A further limitation of conventional incinerators is their inability to mix sufficient combustible fuel with a nonflammable process stream in order to render the resultant mixture flammable and completely combustible.

[0007] Oxygen or oxygen enriched air may be added directly into the combustion chamber for mixing with the gaseous waste streams to increase combustion temperatures, however, oxides, particularly silicon oxides may be formed and these oxides tend to deposit on the walls of the combustion chamber. The mass of silicon oxides formed can be relatively large and the gradual deposition within the combustion chamber can necessitate increased maintenance of the equipment.

[0008] Accordingly, it would be advantageous to provide an improved thermal reactor unit for the combustion of highly resistant contaminates in a gaseous waste stream that provides for high combustion temperatures through the introduction of highly flammable gases for mixing with the gaseous waste stream to insure complete combustion while reducing deposition of unwanted reaction products within the thermal reaction unit.

## SUMMARY OF INVENTION

[0009] The present invention relates to methods and systems for providing controlled combustion of gaseous semiconductor wastes in a thermal reactor while reducing accumulation of deposition products within the system.

[0010] In one aspect, the present invention relates to a two-stage reactor for removing pollutants from gaseous waste streams, the two-stage reactor comprising:

a) an upper thermal reaction chamber comprising:

i) an outer exterior wall;

ii) an interior porous wall, wherein the interior porous wall defines a central combustion chamber, and wherein the interior porous wall is positioned from the outer exterior wall a sufficient distance to define an interior space;

iii) at least one waste gas inlet in fluid communication with the central combustion chamber for introducing a gaseous waste stream therein;

iv) thermal means for combusting the gaseous waste stream, thereby forming reaction products;

v) means for introducing a fluid under pulsing conditions into the interior space, wherein the interior porous wall provides for transference of the fluid from the interior space into the central

combustion chamber at a sufficient force to reduce deposition of reaction products on the interior porous wall;

b) a lower reaction chamber comprising:

i) a gas flow chamber in fluid communication with the central combustion chamber comprising an inlet and outlet for passing the gaseous waste stream and reaction products therethrough;

ii) at least one oxidant inlet positioned to introduce an oxidant to the gas stream flow chamber; and

iii) a liquid vortex positioned near the inlet of the gas flow chamber, wherein the liquid vortex comprises means for generating a downwardly flowing liquid film on interior surfaces of the gas stream flow chamber thereby reducing deposition and accumulation of particulate solids thereon.

[0011]In yet another aspect, the present invention relates to a system for controlled combustion of gaseous pollutants in a gaseous waste stream, the system comprising:

a) an upper thermal reaction chamber comprising:

i) an outer exterior wall;

ii) an interior porous wall, wherein the interior porous wall defines a central combustion chamber and wherein the interior porous wall is positioned from the outer exterior wall a sufficient distance to define an interior annular space;

iii) means for introducing a fluid under pulsing conditions to the interior annular space, wherein the interior porous wall provides for transference of the fluid from the interior annular space; into the central combustion chamber at sufficient pressure or velocity to reduce deposition of reaction products on the interior porous wall;

vi) thermal means for combusting the gaseous waste stream, thereby forming reaction products;

v) at least one waste gas inlet for conducting the gaseous waste stream into the upper thermal reactor, the waste gas inlet comprising a conduit terminating with a portion of the conduit within the central combustion chamber wherein the portion of the conduit is located within a tube which projects beyond the end of the conduit to define a chamber within the tube for flame formation, the tube having an open end communicating with the central combustion chamber;

[0012]a lower reaction chamber comprising:

i) a gas flow chamber in fluid communication with the central combustion chamber;

ii) at least one oxidant inlet positioned to introduce an oxidant to the gas stream flow chamber; and

iii) a liquid vortex positioned between the central combustion chamber and the gas stream flow chamber, wherein the liquid vortex comprises means for generating a downwardly flowing

liquid film on interior surfaces of the gas stream flow chamber thereby reducing deposition and accumulation of particulate solids thereon.

[0013] Preferably, the liquid vortex comprises:

(i) an outer shell having a top plate, a central opening in fluid communication with the central combustion chamber;

(ii) a conical-shaped baffle within the outer shell having an inner surface and a central opening which is generally aligned with the interior surface of the gas stream flow chamber, the conical-shaped baffle generally concentrically aligned with the inner surface of the outer shell to form a concentric chamber; and

(iii) a liquid inlet arranged to tangentially introduce liquid into the concentric chamber, thereby filling the concentric chamber with liquid to create a swirling motion, causing the liquid to rise and overflow the conical-shaped baffle into the gas stream flow chamber to form a laminar sheet of fluid on the inner surface of the conical-shaped baffle that flows downwardly onto the interior surface of the gas stream flow chamber.

[0014] By such arrangement, the gas stream entering the gas stream flow chamber is prevented from directly contacting the walls in the lower portion of the structure. The falling film of water from the "vortex" resists particulate solids accumulating on the

interior wall surfaces of the gas stream flow chamber. The motive liquid stream on such wall surfaces carries the particulates in the gas stream contacting the water film, downwardly for discharge from the gas stream flow chamber.

[0015] In the upper reaction chamber, the interior porous wall may comprise a sintered ceramic body, a sintered metal or any material having fine pores throughout the material for transference of fluid therethrough regardless of the pore size or mesh size. Preferably, the pores are uniformly distributed throughout the material. The material may include pores or perforations of a size to permit fluids to be easily ejected through the interior wall to the combustion chamber at a sufficient velocity to reduce movement of reaction products towards the interior surface of the combustion chamber. For example, there may be on the order of 40 to 1400 perforations per square inch having a diameter that is determined by the number of perforations.

[0016] In the alternative, interior porous wall may comprise a material comprising a plurality of tapered protuberances having a generally funnel-like configuration, which narrow in the direction of the combustion chamber. These conical shaped pores provide for the passage of fluid into the central combustion chamber while reducing backflow of any fluid or reaction products into the interior annular space or depositing on the interior surface of the central combustion chamber.

[0017] The separation between the outer exterior wall and the interior porous wall provides for an interior space that is sufficient to distribute a gas, preferably under

pressure, over essentially the entire exposed interior porous wall. In the alternative the interior porous wall may comprise a multiplicity of apertures or nozzles for introducing the gas into central combustion chamber.

[0018] The fluid may be of any gas such as air and/or an inert gas that is preferably pressurized to a suitable pressure that upon ejection is sufficient to reduce deposition on the inner surface of the central combustion chamber. In operation, the pressurizable gas is at a sufficient pressure to be ejected through the interior porous wall at a velocity that is higher than the velocity of the particle or corrosive gases within the gas stream approaching the wall in the upper reaction chamber, thereby creating a zone in the combustion chamber adjacent to the interior porous wall that inhibits the movement of particles towards the interior surface of the combustion chamber. Generally, the gas may be pressurized in a range of from about 50 to about 600 psig, and more preferably from about 60 to about 100 psig, however, this is easily adjusted by one skilled in the art by determining the flow rate measurement of the gaseous stream into the combustion chamber. Thus, the velocity of the escaping gases through the interior porous wall can be adjusted to be equal to or greater than that of the any reaction products in the gaseous stream in the combustion chamber.

[0019] Preferably, the fluid ejected into the combustion chamber through passage of the interior porous wall is in a pulsing mode. Generally, the pulsing duration of the ejected fluid is from about 3 ms to about 1s, more preferably from about 20 ms to about 100 ms.

[0020] In yet another aspect, the present invention relates to a method for controlled combustion of gaseous pollutants in a gaseous waste steam by treatment in a two-stage thermal reactor, the method comprising;

i) introducing the gaseous waste stream to an upper thermal reactor through at least one inlet end;

ii) providing at least one combustible fuel for mixing with the gaseous waste stream to form a fuel rich combustible gas stream mixture;

iii) igniting the fuel rich combustible gas stream mixture in a combustion chamber to effect formation of oxidized reaction products;

iv) injecting an additional fluid into the combustion chamber contemporaneously with the combusting of the fuel rich combustible gas stream mixture, wherein the additional fluid is injected in a pulsating mode and in a circumventive pattern within the combustion chamber thereby inhibiting deposition of the reaction products in the interior of the combustion chamber;

v) flowing the stream of reaction products into a lower reaction chamber while introducing into the stream an air-containing gas thereby providing a fuel lean mixture; and

vi) flowing the stream of reaction products through a water vortex positioned near the entrance of the lower reaction chamber, wherein water falling from the water vortex inhibits deposition of the reaction products on interior surfaces of the lower reaction chamber.

[0021] Other aspects and advantages of the invention will be more fully apparent from the ensuing disclosure and appended claims

## BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Figure 1 is a partial cut-away view of the elevation of a two-stage thermal reactor according to the present invention.

[0023] Figure 2 is a partial cut-away view of an intake nozzle with an integrated burner according to the invention for introducing a gaseous waste stream from a processing facility into the thermal reactor.

[0024] Figure 3 is a partial cut-away view of an upper thermal reaction chamber illustrating transference of a fluid from the interior annular space into the central combustion chamber.

[0025] Figure 4 is a cut away view of a liquid vortex design according to the present invention.

## DESCRIPTION OF PREFERRED EMBODIMENT OF THE INVENTION

[0026] With reference to Figure 1, there is shown a two-stage reactive 10 representative of the system described herein. There is shown an upper reaction chamber 12 and a

lower reaction chamber 14. The upper reaction chamber includes at least one waste gas inlet 15 for introducing the gaseous waste stream. In this embodiment, there are additional independent gas inlets 16 and 17 for the introduction of additional flammable gases or oxidants to provide a fuel rich gas mixture and thereby increasing the combustion temperature within the system for destruction of resistant contaminates.

[0027] The upper reaction chamber further comprises an outer exterior wall 20 made of an ordinary metallic material and an interior wall 22 made of a porous material that circumvent a central combustion chamber 24. The interior porous wall is positioned from the outer exterior wall a sufficient distance to define an interior annular space 26. The annular space 26 is provided for introducing a fluid, preferably pressurized, which enters the annular space through port 27 and exits the annular space through the interior porous wall 22 to pulse outwardly 30 through the interior porous wall and/or downwardly along the inside surface of the interior porous wall 22. The pulsing ejection of the fluid through the interior porous wall and into the central combustion chamber reduces and/or alleviates the build-up of particulate matter on the interior surface of the central combustion chamber. Preferably, the pulsing gas exits through the interior porous wall at a velocity that exceeds the velocity of any particles that may be in the gas stream within the combustion chamber and approaching the interior wall, thereby causing a non-deposition zone adjacent to the interior wall of the combustion chamber and reducing any deposition of particles on the interior surface of the combustion chamber.

[0028] The mixed gases, with any entrained particles, exit the upper thermal chamber and flow into the lower reaction chamber 14 which comprises a gas flow chamber 32, at least one inlet 34 for introduction of an oxidant, preferably, in an amount sufficient to transform the gas stream from the central combustion chamber from a fuel rich to a fuel lean mixture. The lower reaction chamber further includes a liquid vortex 33, wherein liquid enters tangentially into outer concentric chamber 36 through inlet 38 to create a swirling motion, causing the liquid to rise and overflow baffle 40 into the gas flow chamber 32 to maintain a continuous liquid film on the inner surface of the gas flow chamber, thereby reducing deposition on the interior surfaces of the baffle 40 and gas flow chamber 32.

[0029] Figure 2 shows waste gas inlets 15 for introducing a gaseous waste stream for processing in the two-stage thermal reaction system. In this embodiment, there are multiple independent gas inlets 16 and 17 for introduction of a fuel gas and/or oxidant for mixing with the gaseous waste stream to provide a fuel rich mixture to increase the combustion temperature. The waste gas inlet tube 15 continues past the reactor wall 44 of the central combustion chamber terminating with an extension 45. The mixed gases exit the extension 45, however not directly into the central reaction chamber 24, but instead into a concentric tube 46 for thermal combustion and/or oxidation therein. Preferably, combustion in the tube 46 is facilitated by a pilot burner of the conventional type, positioned within tube 46 or near the downstream end of same and utilizing a sparking plug or hot surface for ignition. A mixed stream of a fuel and a combustion

assisting gas, e.g., a propane, methane or hydrogen gas and air, can be supplied through passages 16 and/or 17 and combined with the gaseous waste stream injected into inlet 15.

[0030] In the alternative, an electrically heated unit, heated in any suitable manner, such as by electrical resistance heating, infrared radiation, microwave radiation, convective heat transfer or solid conduction may be used in the present invention. The temperature of the mixture of gases and gas flow are selected such that the flame can be produced within the concentric tube 46, 24 or both.

[0031] Inlet 16 can be utilized for introducing air between the waste inlet tubes and the reaction chamber for mixing with the gaseous waste stream. Inlet 17 is provided for introducing oxygen or natural gas as a flammable fuel for increasing the combustion temperature to a sufficient reactive temperature for remediation of the gaseous waste stream. The separate inlets permit control of oxidation, reduces the probability of incompatible gas stream mixing and permit active inlet pressure control independent of these parameters being utilized at adjacent inlets.

[0032] Referring to Figure 3, there is shown an upper thermal reaction chamber according to the present invention. The exterior outer wall 20 may be any material so long as it has a predetermined heat resistance and strength and it can be joined securely at junctions by welding, flange coupling, etc. The interior porous wall 22 may include any porous material as long as it satisfies the heat resistance and strength requirements and may include sintered ceramics or sintered metals or the like having sufficient porosity for

transference of fluids from the annular space to the central combustion chamber. Sintered ceramics may include, but are not limited to $MgAl_2O_4$, $Al_2O_3$ or SiC wherein the porous material has a porosity from about 30 % to about 80% and a pore size radius ranging from about 15 nm to about 2 um.

[0033] A gaseous waste stream enters through inlets 15 (not shown) at the top of the reactor and after combustion in tube 46 (not shown) enters into the central combustion chamber 24. Additional gases or fluids are introduced, under pulsing conditions, into the central combustion chamber 24 as indicated by arrows 30 through interior porous wall 22. The gas or fluid is introduced through inlet 27 into an annular space 26 formed between the outer exterior wall 20 and the interior porous wall 22. The fluid retained in the annular space moves or diffuses through the interior porous wall 22 into the central combustion chamber at a sufficient velocity and/or pressure to cause a non-deposition zone adjacent to the interior surface of the central combustion thereby reducing deposition of unwanted reaction products on the inner surface of the central combustion chamber.

[0034] Preferably, the pulsing gas or fluid is pressurized and pulsed through the interior wall 22 or along the wall in a periodic way, such that particulate does not excessively build up or agglomerate into large and difficult to remove deposits. The pulsation magnitude and period depends on the type and quantity of the particulate forming material, the temperature of the reactor and can easily be determined by one skilled in the art.

[0035] The fluid inlet 27, which is positioned on the outer exterior wall 20, provides for the pressurized fluid such as compressed air to be supplied into annular space 26. In the alternative, a plurality of inlets may be used along the length of the outer exterior wall for even distribution and introduction of the pressurized fluid into the annular space

[0036] The pressurized fluid may include any gas such as air and an inert gas, which is compressed to a suitable pressure, such that the gas can pass through the pores of the interior porous wall 22 to reduce and /or remove unwanted reaction products while not affecting the combustion treatment in the central combustion chamber.

[0037] The pressurized fluid may include an oxidant such as clean dry air (CDA) that may be joined in supply relationship to inlet 27 and the thus-introduced air flows into the annular space between outer wall 20 and interior porous wall 22. Alternatively, the air may be heated to a suitable temperature and then flowed through orifices or pores in the interior porous wall 22. In such a way, the oxidant may be added to mix with the effluent gas and form an oxidizable effluent gas mixture for thermal oxidation in the reactor.

[0038] The fluid is preferably ejected into the combustion chamber in a pulsating mode. Any device capable of introducing a fluid in a pulsing mode having a pulsating duration of from about 3 ms to about 1 s may be used in the present invention.

[0039] The pulsating condition is supplied in the form of successive pulse trains wherein the gas quantity in each pulse train is controlled in accordance with the time interval of each pulsation duration. The time interval between pulse trains can be regulated in such a manner that results in a specifiable average flow of the gas. The total flow of the gas to the interior space is regulated by adjusting the time interval between the various pulse trains. A regulating unit 23, as shown in Figure 3, which preferably is a microprocessor, is in communication with a control means 25, for example a valve, for adjusting the gas flow in this manner. A flow meter may also be included to generate and transmit a signal to the regulating unit 23 and this flow signal can function as a feedback signal for regulating the volume in each gas pulse. Each gas pulse is initiated by virtue of the fact that the control means (valve) 25 is opened in accordance with an input program in the microprocessor-regulated unit 23, and each gas pulse can be shut-off or terminated when the signal from a flow meter indicates that a desired volume has passed through the flow meter. An operator may adjust the pulse duration in the regulating unit according to the different properties of the incoming gas, such as viscosity, temperature, or pressure.

[0040] In another preferred embodiment, particle deposition can be mitigated by introducing water into the annular space 26 for pulsing through the interior porous wall 22 or along the walls. In the case of steam flow through the interior porous wall, demineralized water may be contacted against the back of the interior porous wall in the annular space 26 and drawn into and through the porous material by capillary action. The water migrates towards the hot inner surface, receiving heat from the hot reactor gases, via heat conduction in the wall material. As the heat increases and the water migrates

nearer to the hot inner surface of the combustion chamber, the water is converted to steam within the porous material and near the inner surface of the combustion chamber, which as a result of the high volume of vapor, is then ejected from the inner wall with sufficient force to remove adhering particulate deposits. The water and steam flow can into the annular space may be periodic or continuous. Continuous introduction of water into the annular space provides for the interior porous wall 22 to be immersed in water thereby exposing the entire surface of the porous wall to the effects of the capillary phenomenon and provide for replenishing water that has been evaporated from the surface of the porous wall 22.

[0041] In the case of periodic flow, the change in thermal conditions can promote differential thermal expansion forces, thereby aiding in the cracking and removal of strongly adhering particulates. Because of capillary forces in the wall material, a considerable particle removal force, or pressure can be achieved, even if the water source pressure is low.

[0042] For the case of steam flow along the walls, demineralized water is converted into steam, via heat and the stream is distributed through either stationary of movable nozzles, to remove particulate adhering to the wall surface. By pulsating the nozzles, thermal differential expansion effects can assist to break and remove wall deposits.

[0043] The interior porous wall 22 may be of suitable porous construction, and may for example comprise a porous sintered metal, perforated metal sheet, porous plastic, or

porous ceramic wall. Preferably, the porous material provides for pores of sufficient size for transference of a fluid therethrough and that may, for example, be in the range of from about 0.5 micron to about 30 microns.

[0044] Figure 4 illustrates the liquid vortex 33 of the present invention. The reacted gases exit the upper reaction chamber at the bottom of the chamber through a vortex of cooling water. As shown in Figure 4, the water vortex unit generally comprises a top plate 50, an outer shell 36 and a generally cone-shaped baffle 40. The outer shell 36 comprises a liquid inlet 38. The liquid inlet 38 is arranged in relation to the outer shell 36 such that as liquid is introduced tangentially into the outer shell 36, the concentric chamber 37 is filled with liquid to create a swirling motion, causing the liquid to rise and overflow the cone-shaped baffle to form a laminar sheet of fluid on the inner surface of the baffle that flows downwardly onto the interior surface of the gas stream flow chamber 39, thereby cooling the interior surface and reducing deposition of particulates thereon.

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[0045] Although the invention has been variously described herein with reference to illustrative embodiments and features, it will be appreciated that the embodiments and features described herein above are not intended to limit the invention, and that other variations, modifications and other embodiments will readily suggest themselves to those of ordinary skill in the art, based on the disclosure herein. The invention therefore is to be broadly construed, consistent with the claims hereafter set forth.